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Constant Pressure Water Supply System Control Using PLC

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(Abstract) On the basis of the constant-pressure principle and variable-frequency principle applied to traditional water supply system, this paper presented the overall structure of water supply system using plc (programmable logic controller) as main controller, and newly used the switched adaptive control principle to optimize water supply quality. The systematic analysis was carried on by combining the system with its mathematical model. The simulation data using visual c++ confirms the system's rationality, stability and superiority.

Keywords: Constant-Pressure Water Supply; Switched Adaptive Control; PLC; VVVF.

1. INTRODUCTION

Available water on the earth is being less and less, while people's demand of water supply is increasingly rising. As a result, water supply has drawn many experts and scholars' attention in recent years. Water supply system in china generally includes gravity water supply, air-pressure water supply and traditional constant-pressure water supply [1]. Gravity water supply system needs to build towers or high water tanks and its stability influenced by storage capacity is not easy to control. Air-pressure water supply system adjusts water pressure using closed air-pressure tank and its reliability is greatly affected by changes of air. Traditional constant-pressure water supply system has simple and reliable structure, but it can not meet the need of modern water supply. Therefore, water supply system of energy-efficiency, automation and reliability is in urgent need of development[2]. From comprehensive comparison of the above ways, this paper designed a water supply system to maintain constant pressure basically in 24 hours with the help of switched adaptive control theory.

2. SYSTEM OVERVIEW

As known to us all, water is delivered to each user through pipelines from water company. The system using switched adaptive control algorithm can provide stable, efficient and reliable water supply.

2.1. Brief Introduction of the System

Water flows into the switched adaptive control system through pipelines and then will be delivered to every user with constant-pressure. The system can automatically adjust and switch operating parameters according to changes of water consumption and the demand of constant -pressure. Shown in **figure 1**, the system mainly consists of plc control body and switched adaptive control body. Plc control body includes CPU (Central Processing Unit), pressure transmitters (Attached in every tap), converters, etc. The main theoretical basis is the combination of MRAC (Model Reference Adaptive Control) and SS (Switched System).

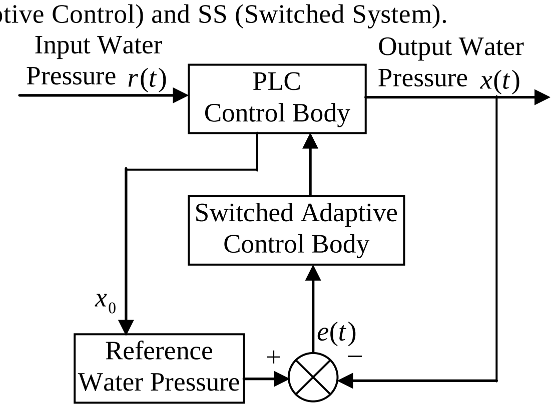

Figure1. Block diagram of the system

2.2. Structural Composition of PLC Control Body

Plc is core controller of the system. It sets reference water pressure (general water pressure $1.5\text{-}2.5kg/cm^2$) through its internal programs. Reference pressure is compared with real-time ones monitored by pressure transmitter to get deviation. Then, based on the deviation and switched adaptive control algorithm, plc gives appropriate instructions to converter. Converter, according to established switching modes, alters status of pump groups to keep water pressure constant. Pressure transmitter embedded a/d (analog/digital) inverter is of the latest intelligent digital type, and can communicate directly with plc via rs (recommended standard) 232/485. all the components constitute a stable closed-loop control system.

As shown in **figure 2**, *r(t)*, real-time water pressure in

pipelines, flows into the plc control body, and then output stable water pressure *x(t)*.

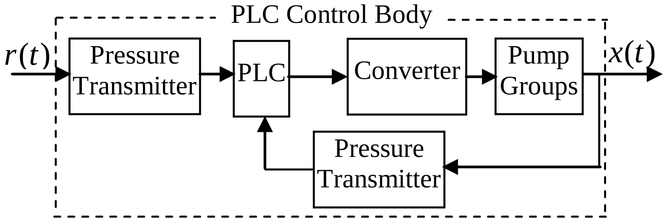

Figure2. block diagram of plc control body

3. THEORETICAL ANALYSIS

Most of the existing water supply system use ac (alternating current) variable-frequency technology, that is, mcu (micro controller unit), as core controller, monitors real-time water pressure and controls the system. But its features, like nonlinear, large inertia, time delay and so on, make the classical control theory out of use. Then modern advanced control theory is chosen to satisfy the control need.

3.1. Constant-pressure Principle

As in different regions, different time, and different seasons, water consumption is of great uncertainty, and it is hard to express with a fixed or unified mathematical model. Feedback principle tells that to maintain a physical constant or fundamental unchanged should introduce reference value to compare with and form a closed-loop system [3]. In accordance with the above principle,

(1) if water supply> water consumption, pressure rises.

(2) if water supply= water consumption, pressure keeps constant.

(3) if water supply< water consumption, pressure drops.

Thus, making water supply and consumption remain dynamic balance can achieve constant pressure, that is, real-time water pressure of pipelines basically equals to reference one during dynamic balance.

3.2. Principle of Variable-frequency Control

Variable-frequency control is to adjust ac motor's drive power frequency to change its speed in the use of converter. It not only can change speed continuously, but also can adjust the relationship between voltage and frequency based on load characteristics so that motor is always running efficiently. Pump groups in the system are controllable actuator. To control pumping capacity by adjusting motor speed can maintain constant water pressure. Principle of variable-frequency control in detail as follows,

- Slip of asynchronous motor

$$S = 1 - (n/n_1) \quad (1)$$

- Synchronous speed of asynchronous motor

$$n_1 = 60\, f/P \quad (2)$$

- Speed of asynchronous motor

$$n = 60 f\,(1 - S)/P \quad (3)$$

Where,

n_1 : ideal load-free speed of asynchronous motor

n : rotor speed of asynchronous motor

f : stator power frequency of asynchronous motor

P : pole pair number of asynchronous motor

From **eq.3**, when pole pair number *p* remains the same, motor rotor speed *n* is proportional to stator power frequency *f*. Thus, to adjust rotor speed *n* of asynchronous motor can adjust the motor's synchronous speed n_1 by altering its stator power frequency *f* smoothly [4].

3.3. Switched Adaptive Control Theory

SS (Switched System) is composed of a series of switched subsystems and certain switched rules, in which subsystem may be stable or unstable and switched rule can be fixed or random. The whole SS is controlled by switched rule called switched law, switched signal, switched strategy or switched function. SS is an important branch of hybrid system defined as the combination of DEDS (Discrete Event Dynamic System) and CVDS (Continuous Variable Dynamic System).

Adaptive system has a certain ability to adapt to changes of environmental conditions (such as load change, climate change, etc.) and can automatically regulate control actions to get desired or optimal results. As **Figure 3** shows, the system, using reference input *r(t)*, control input *u(t)*, object output *y(t)* and known external interference, grasps its current performance, compares with given performance index and makes decision [5].

This paper integrates the above two control theories to form the so-called switched adaptive control algorithm. It can solve part of the problem during frequency switching. The switched theory is mainly used to control converter to adjust motor's speed for energy saving, while the use of MRAC can help the system regulate its operating parameters to expand its application.

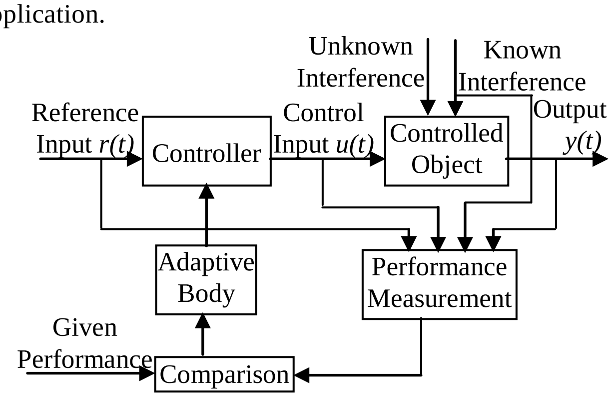

Figure3. Block diagram of adaptive control system

4. SYSTEM MODELING AND SIMULATION

From **Figure 1**, the system is equivalent to a SISO (Single Input Single Output) one, that is, real-time water pressure is input of the system and constant water pressure is the output.

4.1. Mathematical Modeling

Intelligent digital pressure transmitter monitors real-time input and output water pressure. Its outcome is accurate, but pressure measurement is of great time delay. So compensation is needed to ensure the accuracy of real-time data.

On the basis of variable-frequency control theory, choose

$$V/f = kC_0 \tag{4}$$

PWM (Pulse Width Modulation) mode,

Where,

V : Output voltage of converter

f : Output frequency of converter

C_0 : Nonnegative constant

k : n discrete nonnegative constants (n determined by the number of interfering factors)

Consider characteristics of the system, assuming *n=4*, namely, *k* has four discrete nonnegative constants. Based on the features of various interference factors, the values of *k* show in TABLE1.

Table 1. Value of k

k	k_1	k_2	k_3	k_4
Value	0.5	1.0	2.0	0.0

Corresponding to **Table 1**, customized converter frequency-voltage curve shows in **Figure 4**.When converter is at startup or very low speed, motor's output voltage is low as well, which makes the motor not get enough rotational force, so the initial start point moves to point *(0, V_0)* as a compensation for torque. Motor can start or run properly at point *(F_1, V_1)* when increasing slope can save energy. At point *(F_2, V_2)*, the slope soars to ensure steady water supply during peak period. Point *(F_3, V_3)* is the rated saturation point of converter, where output voltage does not vary with frequency.

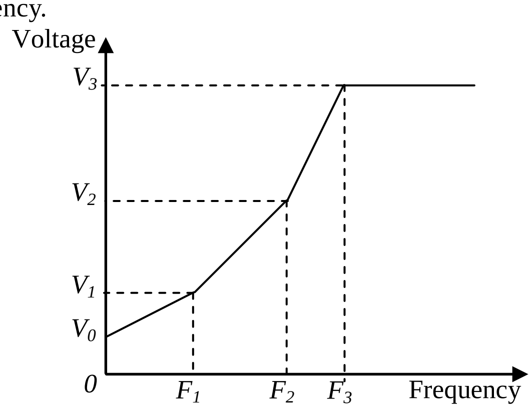

Figure4. Customized converter frequency-voltage curve

The purpose of speed regulation in the system is to change pump's water output and lift. However, pump's curve fitting and the optimization of speed regulation strategy also need compensation.

Summarizing the above analyses, introduce a PI controller for the system to compensate all the mentioned shortages.

$$G_c(s) = K_p(1+\frac{1}{T_i s}) \tag{5}$$

Where,

$s \underline{\underline{\Delta}} \frac{d}{dt}$: Ordinary differential operator

K_p : Proportional gain

T_i : Integration time

From **Figure 2**, we can see that PLC controls converter directly, that is, output of PLC is converter's input. The output of PLC is

$$e_0(t) = x_0 - x(t) \tag{6}$$

Where,

$e_0(t)$: Real-time water pressure deviation

$x(t)$: Real-time output water pressure

x_0 : Reference constant water pressure set by PLC program (generally $1.5-2.5kg/cm^2$).

$e(t)$ is water pressure deviation compensated by PLC, and then converter's input is

$$e(t) = e_0(t)G_c(s)\,. \tag{7}$$

According to the working principle of converter

$$e(t)/V(t) = \text{sgn}(e(t))K_0 \tag{8}$$

Where,

$\text{sgn}()$: Signal function

$V(t)$: Real-time output voltage of converter

K_0 : Nonnegative constant (differing from the type of converter).

From **Eq.7** and **Eq.8**, the output voltage of converter is

$$V(t) = \frac{e_0(t)G_c(s)}{\text{sgn}(e_0(t)G_c(s))K_0}\,. \tag{9}$$

Substitute **Eq.9** into **Eq.4**, then the output frequency of converter is

$$F(t) = \frac{e_0(t)G_c(s)}{\text{sgn}(e_0(t)G_c(s))K_0 kC_0}\,. \tag{10}$$

Substitute **Eq.10**into **Eq.3**, then the motor speed is

$$n(t) = \frac{60(1-S)e_0(t)G_c(s)}{\text{sgn}(e_0(t)G_c(s))K_0 kC_0 P}\,. \tag{11}$$

The similarity principle of pump shows that when speed changes, flow is proportional to the speed, that is

$$Q(t) = K_q n(t) \tag{12}$$

Where,

$Q(t)$: Real-time water output of pump

K_q : Proportional modulus (Calculated based on the parameters of pump itself)

As pump's water output directly determines the output water pressure, *Q(t)* will be equivalent to the output of the system, thus forming a complete switched adaptive control

structure.

4.2. System Simulation

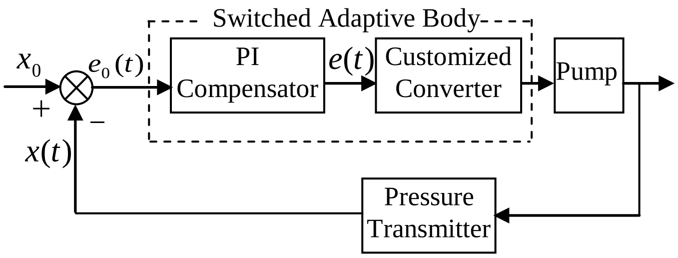

Figure5. Block diagram of switched adaptive body

Based on the above mathematical modeling, the corresponding block diagram of switched adaptive body is shown in **Figure 5**. From field debugging experience, take *Kp=12.63, Ti=12.63/0.087* and the reference water pressure $x_0=2.0$, then using Visual C++ programming and virtual sampling time, the simulation data are shown in **Figure 6** and **Figure 7**. In order to analyze the simulation data, defined the rate of deviation as

$$R_d = \frac{|\text{RT.} - \text{Ref.}|}{\text{Ref.}} \times 100\% \tag{13}$$

and the rate of change as

$$R_c = \frac{|\text{RT.2} - \text{RT.1}|}{\text{RT.2}} \times 100\% \tag{14}$$

Where,

RT. : Real-time output water pressure

Ref. : Reference water pressure

In **figure 6**, the data were collected every ten minute within one hour (virtual time), corresponding to six real-time output water pressures. As choosing random numbers to simulate real-time input water pressure, real-time output water pressure varied with them. But their rates of deviation rd and change *rc* were small, the largest *rd* was 0.65% and the largest *rc* was 1.06%. **Figure 7** was obtained by monitoring the system for 24 hours, and the simulation system outputted a real-time water pressure at each hour (virtual time). During different time periods, real-time output water pressure differed a lot, but they all fluctuated around reference one, namely, the system could generally adjust to changes and remain stable by altering operating parameters with the help of switched adaptive control technology.

D:\Visual C++\CYuYan\bin\wwtemp.exe

Time	10	20	30	40	50	60
Ref.	2.000	2.000	2.000	2.000	2.000	2.000
RT.	2.010	2.011	2.004	1.992	2.008	1.987

Press any key to continue

Figure6. Data collected within one hour

D:\Visual C++\CYuYan\bin\wwtemp.exe

NO.	1	2	3	4	5	6
Ref.	2.000	2.000	2.000	2.000	2.000	2.000
RT.	2.005	2.010	2.000	1.993	2.008	1.997
NO.	7	8	9	10	11	12
Ref.	2.000	2.000	2.000	2.000	2.000	2.000
RT.	1.995	2.000	2.011	1.999	2.002	1.999
NO.	13	14	15	16	17	18
Ref.	2.000	2.000	2.000	2.000	2.000	2.000
RT.	1.998	2.003	2.007	1.995	2.005	1.999
NO.	19	20	21	22	23	24
Ref.	2.000	2.000	2.000	2.000	2.000	2.000
RT.	1.991	2.000	2.001	1.999	2.000	1.999

Press any key to continue

Figure7. 24-hour real-time monitoring data

5. CONCLUSION

From the comparison between reference water pressure and the real-time output ones shown in **figure 6** and **figure 7**, there were fluctuations, but their rates of deviation and change were to the extent permitted, which means the system basically remained dynamic balance and stable operation. The high reliability and stability of the system confirms its good characteristics.

The system introduced in the paper usually uses to high buildings, urban residential areas and so on. It upgraded existing constant-pressure water supply system and improved current water supply technology by using switched adaptive control algorithm. Because the system switching by itself can achieve a good water supply effect, and the pumps can start or stop automatically based on the real-time signals. Switching variable-frequency step-less speed regulation technology used in the system to control water pressure also can reduce mechanical losses. The new method ensures the system can maintain constant water pressure basically in 24 hours. It is more stable and reliable with the use of plc. The modeling and simulation of the modified system demonstrated its superiority. It will be able to further its promotion and development in the future.

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